FINAL REPORT

I. Grant Details

Report Title: Commercialization of Ultrasonic Device for Measuring the Fat Content of Mackerel

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II. Abstract

The over exploitation of certain fish species has meant that the fishing industry has directed its attention towards the use of underutilized species, such as mackerel. The effective utilization of mackerel largely depends on its fat content and therefore the fishing industry requires analytical techniques to rapidly grade mackerel according to its composition. We have developed a hand-held ultrasonic device that can be used to provide information about fish composition. The composition is determined from measurements of the ultrasonic velocity of fish, either at a fixed temperature or over a range of temperatures. A series of empirical equations were developed to relate ultrasonic velocity measurements to fish composition. We demonstrated that the compositions determined using the ultrasonic velocity technique were in good agreement with those determined by official methods for a number of fish species, including cod, mackerel, salmon and tuna. The technique is now at the stage where a commercial instrument manufacturer could develop it, providing there is sufficient interest and a big enough market in the fishing industry.

III. Executive Summary

This project has shown that the composition of mackerel (fat content and solids-non-fat) can be determined by measuring its ultrasonic velocity as a function of temperature. It is possible to determine the fat content without knowing the solids-non-fat content by measuring the ultrasonic velocity at a single high temperature (> 25 /C). However, this procedure may be destructive because protein denaturation occurs at these relatively high temperatures. In addition, mackerel are usually captured, stored and processed at lower temperatures, which may limit the direct application of the ultrasonic technique for fat content measurement in practice. On the other hand, the fat content could rapidly be determined in the laboratory, either by making measurements at a single temperature or by making measurements over a range of temperatures. The solids-non-fat content can be determined without knowing the fat content by measuring the ultrasonic velocity at a relatively low temperature (< 10 /C), which may be useful for many applications. Whether a fish has been frozen or not can be determined by measuring the ultrasonic attenuation coefficient over a range of temperatures.

IV. Purpose

A. Description of Problem. The over exploitation of certain fish species has caused the fishing industry to direct its attention towards the use of fish species that are currently underutilized. Mackerel has been identified as a major source of underutilized fish in the U.S., being harvested at less than half its sustainable yield. The effective utilization of mackerel depends largely on its fat content. High fat content fish (> 15%) have great value on international markets, whereas low fat content fish (< 15%) are more desirable for domestic use. The fat content of mackerel varies significantly depending on the time of year, geographic location, sex and size of the fish. Although trends have been established between these parameters and the overall fat content of fish (*e.g.* fat content is usually higher in the Fall), significant variations are observed, even within a single landing of fish. This makes it difficult for fish processors to accurately grade the fat content of mackerel based solely on factors such as the season that the fish was harvested. Traditional methods of determining fat content are unsuitable for routine analysis because they are time consuming, labor intensive and destructive. Consequently, it has been recognized that there is an urgent need for the development of a rapid, accurate and nondestructive method of classifying mackerel according to their fat content.

A preliminary study indicated that ultrasonic velocity measurements may provide a cost-effective method of rapidly grading mackerel according to their fat content ("Development of a Rapid Non-Destructive Technique to Measure the Fat Content of Mackerel" - SK Award Number NA66F0020). The objective of the current project was to continue this work so that a rapid and economically viable instrument could be developed that would be useful for the fishing industry.

B. Objectives.

- Optimization of the *Ultrasonic Fat Meter* developed in the previous project so that it could be used as a hand-held device that could be purchased commercially by the fish processing industry.
- Development of a database relating the ultrasonic properties of mackerel to their fat content over the temperature range typically encountered in practice.
- Work with an ultrasonic instrument manufacturer to develop inexpensive versions of the Ultrasonic Fat Meter that could be purchased commercially.

V. Approach

A. Description of Work. After surveying the various types of low-cost ultrasonic equipment that were commercially available we purchased a small hand-held ultrasonic velocity meter from a local instrument manufacturer (25DL Ultrasonic Thickness Gage, Panametrics, Waltham, MA). This device was actually designed to measure the thickness of metals and polymers when only one side of the material is inaccessible, but we modified it so that it could be used to measure the ultrasonic velocity of fish samples. The device was battery operated, was small enough to be carried by an operator and gave out a measurement directly on the front-panel. It is therefore suitable for general use in the fishing industry. The device measures the time-of-flight of an ultrasonic pulse through a fish sample. The time-of-flight can then be converted into an ultrasonic velocity using a suitable calibration chart or a computer program. The ultrasonic velocity can then be used to obtain information about mackerel composition once a suitable mathematical relationship had been established (see below). Preliminary tests were carried out using the hand-held device on a series of calibration samples, which showed that the measurements it produced were comparable to those made by the sophisticated ultrasonic spectrometer developed previously.

Measurements made using the hand-held ultrasonic velocity device on mackerel with different compositions were compared with those made using the more expensive ultrasonic spectrometer developed in the previous study. There was an excellent correlation between the two methods, which showed that the inexpensive and convenient hand-held device could be used instead of the expensive laboratory equipment. The principles of the technique are described in more detail in the attached publications.

The proximate composition and ultrasonic properties of a number of mackerel and other fish species collected at different times were measured so as to develop a database relating the ultrasonic properties of fish to their composition. Semi-empirical relationships between the ultrasonic properties of mackerel and their composition were then established using two different methods. In the first approach a model was developed based on fish analogs. The fish analogs were prepared by homogenizing powdered solids-non-fat (from cod), water and oil in varying proportions--similar to those found in mackerel. The ultrasonic velocity versus temperature profiles of the fish analogs were then measured and empirical equations developed to relate the ultrasonic properties to the composition. In the second approach, the ultrasonic velocity versus temperature profiles and composition of a number of mackerel samples were measured and the mathematical constants required to provide a good fit between an empirical equation and the ultrasonic measurements was developed. These empirical equations could be used to predict the ultrasonic velocity of mackerel of any composition and temperature. The equations developed in this approach are a major step forward in the analysis of muscle foods using ultrasound and are one of the major achievements of this project. The general approach has been published in a series of manuscripts (see below).

We analyzed the influence of lipid oxidation, freezing and storage conditions on the ultrasonic properties of mackerel. The ultrasonic velocity of a fish is sensitive to changes in composition when water is lost due to "drip" after freezing. The ultrasonic velocity and attenuation both increase due to drip, because of the increase in fat and solids-non-fat in the tissue. The ultrasonic attenuation coefficient versus temperature profile can also be used to determine whether a fish has been frozen or not. There is a large increase in the attenuation coefficient in non-frozen fish when they are heated above 20 /C, which is not observed in fish that have previously been frozen. The technique may therefore be used to analyze the whether fish had been previously frozen, which may be important for quality assessment. The ultrasonic technique was not sensitive to changes in the chemical composition of mackerel as measured by TBARS or K-value, and was therefore not useful for assessment of chemical quality.

B. Project Management. The project was managed by Professors D.J. McClements and E.A. Decker. The experiments were performed and analyzed by Drs. V. Suvanich and H. Sigfusson who were hired as Post-Docs.

VI. Findings

A. **Actual Accomplishments.** After surveying the various types of low-cost ultrasonic equipment that are commercially available a small hand-held ultrasonic velocity meter was purchased from a local instrument manufacturer (25DL Ultrasonic Thickness Gage, Panametrics, Waltham, MA). This device is actually designed to measure the thickness of metals and polymers when only one side of the material is accessible, but we modified it so that it could be used to measure the ultrasonic velocity of fish samples. The device is battery operated, is small enough to be carried by the operator and gives out a measurement directly on the front-panel. It should therefore be suitable for general use by fishermen. The device measures the time-of-flight of an ultrasonic pulse that travels through the fish sample being analyzed. The time-of-flight can then be converted into an ultrasonic velocity using a suitable calibration chart or computer program. We have tested the hand-held device on a series of well-characterized samples and shown that the measurements that it produces are comparable to the sophisticated ultrasonic spectrometer developed previously.

The proximate composition and ultrasonic properties of a number of mackerel and other fish species collected at different times were measured so as to develop a database relating the ultrasonic properties of fish to their composition. Semi-empirical relationships between the ultrasonic properties of mackerel and their composition were then established using two different methods. In the first approach a model was developed based on fish analogs. The fish analogs were prepared by homogenizing powdered solids-non-fat (from cod), water and oil in varying proportions--similar to those found in mackerel. The ultrasonic velocity *versus* temperature profiles of the fish analogs were then measured and empirical equations developed to relate the ultrasonic properties to the composition. In the second approach, the ultrasonic velocity versus temperature profiles and composition of a number of mackerel samples were measured and the mathematical constants required to provide a good fit between an empirical equation and the ultrasonic measurements was developed. These empirical equations could be used to predict the ultrasonic velocity of mackerel of any composition and temperature. The equations developed in this approach are a major step forward in the analysis of muscle foods using ultrasound and are one of the major achievements of this project. The general approach has been published in a series of manuscripts (see section VII.B). The proximate composition and ultrasonic properties of a number of mackerel and other fish species collected at different times were measured so as to develop a database relating the ultrasonic properties of fish to their composition. Semi-empirical relationships between the ultrasonic properties of mackerel and their composition were then established using two different methods. In the first approach a model was developed based on fish analogs. The fish analogs were prepared by homogenizing powdered solids-non-fat (from cod), water and oil in varying proportions -similar to those found in mackerel. The ultrasonic velocity versus temperature profiles of the fish analogs were then measured and empirical equations developed to relate the ultrasonic properties to the composition. In the second approach, the ultrasonic velocity versus temperature profiles and composition of a number of mackerel samples were measured and the mathematical constants required to provide a good fit between an empirical equation and the ultrasonic measurements was developed. These empirical equations could be used to predict the ultrasonic velocity of mackerel of any composition and temperature. The equations developed in this approach are a major step forward in the analysis of muscle foods using ultrasound and are one of the major achievements of this project. The general approach has been published in

a series of manuscripts (see section VII.B).

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B. Problems. There were a number of problems that we encountered during the course of the project. Firstly, we found that the ultrasonic properties of mackerel (and other fish species) were particularly sensitive to the solids-non-fat content, as well as the fat content. We therefore had to devise methods to overcome this problem. We found that it was possible to determine both the fat and the solids-non-fat content by measuring the ultrasonic velocity as a function of temperature. This was because the velocity of aqueous solutions increases with temperature, whereas that of fats decreases with temperature. At certain temperatures the ultrasonic velocity only depends on the solidsnon-fat content, whereas at other temperatures it depends only on the fat content. Thus it is possible to prescribe the best temperatures to make measurements to determine fat or solids-non-fat content. A second problem was associated with our attempts to get an ultrasonic instrument manufacturer interested in converting our prototype instrument into a commercial device that could be used by the fishing industry. The companies that we contacted were not convinced that the market for such devices was large enough for them to invest time and money in developing and marketing the instruments.

C. Additional Work. We clearly showed that the ultrasonic properties of fish are sensitive to the fat and solids-non-fat content. An obvious area of additional work would be to get an instrument manufacturer interested in developing a commercial device based on the principles of this project. This would require a survey to establish the potential market for such a device. This may prove to be more economical if it can be shown that the technique could also be used to analyze expensive fish species such as tuna.

VII. Evaluation

A. Attainment of Project Goals. The first two objectives in our project were successfully attained, *i.e.,* development of a low-cost hand-held ultrasonic velocity meter and establishment of a method to relate ultrasonic velocity measurements to fish composition. The third objective was not successful because we were not able to convince ultrasonic instrument manufacturers that the market was sufficiently large to warrant them committing additional personal and resources to developing a commercial ultrasonic fish analyzer. The main modification to the project goals was the need to carry out more extensive calibration experiments than expected because the ultrasonic properties of the fish were both fat and solids-non-fat dependent. We also carried out measurements on a variety of non-mackerel fish species because this enabled us to obtain a greater range of fish compositions for our studies.

B. Dissemination of Project Results. Our results have been disseminated to the scientific community mainly through publication in peer-reviewed scientific journals and by presentations and meetings and conferences:

H. Sigfuson, E. A. Decker, and D. J. McClements. (1999). Development of hand-held ultrasonic device for characterization of the fat content of mackerel. Submitted.

H. Sigfuson, E. A. Decker and D. J. McClements. (1999). Influence of freezing and storage on the ultrasonic properties of Atlantic Mackerel (Somber Scrombrus). Submitted.

H. Sigfuson, E. A. Decker and D. J. McClements. (1999). Ultrasonic characterization of Atlantic Mackerel (Somber Scrombrus). *Food Research International,* Submitted.

V. Suvanich, R. Ghaedian, R. Chanamai, E. A. Decker, and D. J. McClements (1998). Prediction of fish composition from ultrasonic measurements: Cat fish, Cod, Flounder, Mackerel and Salmon. *J. Food Sci.* 63, 966-968.

R. Ghaedian, J. Coupland, E. A. Decker, and D. J. McClements (1998). Ultrasonic determination of fish composition. *J. Food Eng. 35, 323-337.*

V. Suvanich, D. J. McClements, R. Ghaedian, R. Chanamai, and E.A. Decker. Determination of fish composition using ultrasonic velocity measurments. in: IFT Annual Meeting: Book of Abstracts. IFT, New Orleans.

R. Ghaedian, E. A. Decker, J. N. Coupland, and D. J. McClements. (1997). Ultrasonic determination of the fat content of mackerel. in: IFT Annual Meeting: Book of Abstracts. IFT, Orlando.

H. Sigfusson and D. J. McClements (1999). Ultrasonic properties of atlantic mackerel (Scomber Scombrus)--Influence of composition, storage and freezing. in: IFT Annual Meeting: Book of Abstracts. IFT, Chicago.

R. Chanamai and D. J. McClements (1999). Ultrasonic determination of chicken composition. in: IFT Annual Meeting: Book of Abstracts. IFT, Chicago.